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DMIC **review** OF RECENT DEVELOPMENTS

Metals Joining

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NICKEL

A program at General Electric to develop joining techniques for TD Nickel-Chromium is now complete.(1) The program was directed toward the fabrication of jet-engine and aerospace components. Two processes, high-temperature brazing and yield-strength-limited diffusion bonding, were satisfactorily developed for the applications of interest. For high-temperature brazing, TD-6 (Ni-16Cr-4Si-17Mo-5W) was selected as the most satisfactory brazing alloy on the basis of load-carrying ability before and after long exposure (up to 500 hours) at 2000 and 2200 F. Tables 1 and 2 give tensile properties of TD Nickel-Chromium joints brazed with the TD-6 alloy.

Satisfactory spot diffusion bonds were made using three-phase resistance-welding equipment. Bonds that equalled or exceeded the load-carrying ability of the alloy were produced in 0.025- and 0.040-inch-thick material. However, the microstructure of these bonds was not ideal, exhibiting a layer of equiaxed recrystallized grains. Numerous welding-machine settings were investigated in an attempt to eliminate the problem without success.

Tensile-shear-test results for TD Nickel-Chromium spot-diffusion bonds are given in Table 3.

TABLE 1. AVERAGE TENSILE PROPERTIES OF TD-6 BRAZED JOINTS(a) IN TD NICKEL-CHROMIUM(1)

Test Temperature, F	Load at Failure, pounds	Indicated Shear Strength, psi	Failure Location	Base Metal Stress at Failure, psi
Room	2,726	41,800	Braze	90,800
1000	2,398	37,700	Braze	79,800
1400	1,190	17,560+	Base metal	39,700
1800	398	5,930+	Base metal	13,300
2000	301	4,680+	Base metal	10,020
2200	204	3,178	Braze and base metal	6,800

(a) 0.060-inch-thick TD Nickel-Chromium sheet, 0.120-inch overlap, 0.005-inch gap.

TABLE 2. AVERAGE TENSILE PROPERTIES OF TD-6 BRAZED JOINTS(a) IN TD NICKEL-CHROMIUM AFTER HIGH-TEMPERATURE EXPOSURE(1)

Exposure	Test Temperature, F	Load at Failure, pounds	Indicated Shear Strength, psi	Failure Location	Base Metal Stress at Failure, psi
As brazed	2000	301	4,680+	Base metal	10,020
100 hours at 2000 F in vacuum	2000	275	4,130	Braze	8,805
500 hours at 2000 F in vacuum	2000	287	4,410	Braze	9,200
100 hours at 2200 F in vacuum	2000	286	4,290	Braze and base metal	9,330
500 hours at 2200 F in vacuum	2000	277	4,350+	Base metal	9,140
100 hours at 2000 F in air	2000	251	3,460	Braze	8,280
500 hours at 2000 F in Air	2000	235	3,390	Braze	7,690
100 hours at 2200 F in air	2000	246	3,660	Braze and base metal	7,790
500 hours at 2200 F in air	2000	239	3,400	Braze and base metal	7,770

(a) 0.060-inch-thick TD Nickel-Chromium sheet, 0.120-inch overlap, 0.005-inch gap.

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TABLE 3. TD NICKEL-CHROMIUM DIFFUSION BOND TENSILE-SHEAR TEST RESULTS (THREE PHASE)(1)

Material Thickness, inch	Test Temperature, F	Load at Fracture, pounds	Spot Diameter, inch	Indicated Shear Strength, psi
0.025 to 0.025	Room	1370	0.25	27,500
0.025 to 0.025	1800	260	0.24	5,780
0.025 to 0.025	2000	187	0.23	4,630
0.040 to 0.040	1800	271	0.25	5,410
0.040 to 0.040	2000	242	0.27	4,326
0.040 to 0.040	2200	218	0.28	3,553
0.025 to 0.025	2200	158	0.23	3,740
0.040 to to 0.040	Room	2092	0.25	42,266

In the final phase of the program, two jet-engine components were fabricated using the above processes and then tested. A TF39, second-stage turbine-nozzle vane performed satisfactorily when subjected to approximately 1100 engine test cycles. The center two "V" gutter rings of a GE-4 (SST) flameholder were fabricated using either butt or scarfed brazed joints, reinforced by a spot-diffusion-bonded and back-brazed internal doubler. These parts performed satisfactorily in full-scale component tests.

Joining procedures for three nickel-base alloys were developed during a research program to design and fabricate lightweight heat exchangers at Garrett Corporation.(2) The tube-and-shell-type heat exchangers were designed to withstand 100 hours of operation at 1540 to 2140 F. Optimum bonding conditions for these service conditions were selected for Hastelloy X, L-605 (Haynes 25), and TD Nickel. Final recommendations are summarized in the following paragraph.

For 0.003-inch-wall tubes of Hastelloy X, brazing with Nicrobraz 30 alloy (Ni-19Cr-10Si-1Mo-4Fe) at 2175 F in either a vacuum or dry-hydrogen atmosphere was satisfactory. The hydrogen atmosphere provides advantages in temperature-zone uniformity and in the speed of heating and cooling. Close control of the quantity of alloy and of the temperature were found to be critical to prevent erosion of the Hastelloy X by Nicrobraz 30. Tubes of the L-605 alloy having wall thicknesses of 0.006 to 0.010 inch were brazed with J8102 alloy (Ni-15.2Cr-8Si) at 2200 F. Again, both vacuum and dry-hydrogen atmospheres were satisfactory. Alloy L-605 was relatively insensitive to erosion by any of the brazing alloys considered. Several welding processes also proved satisfactory with L-605. It was easily welded by the inert-gas, tungsten-arc process, using either L-605 or Hastelloy W filler wire. Excellent quality spot welding was demonstrated, and two 0.006-inch-thick tubular inserts were successfully laser welded to an 0.008-inch-wall tube. TD Nickel in 0.006 to 0.008-inch-wall thickness was brazed in vacuum using TD-20 braze alloy (Ni-25Mo-16Cr-5W-4Si). However, excess quantities of the TD-20 alloy proved to be erosive to the TD Nickel. During high-temperature exposure, oxidation of the TD Nickel was accelerated at the base of the braze fillet, creating stress risers, limiting the service temperature of the uncoated structure to 1950 F.

North American has reported some new information related to the elimination of weld-associated strain-age cracking in René 41.(3) Resistance to strain-age cracking was found to be improved by a preweld solution anneal at 1975 F with a 40 F per minute cool to 1200 F, and strain-age cracking was found to be eliminated by postweld stress-relieving anneals in high-purity argon or vacuum. Cracking in most heats of René 41 also can be eliminated by rapid heating, on the order of 50 F per minute, through the age-hardening temperature range. During this study, low carbon content was shown to be extremely detrimental to strain-age cracking. The probable relation of oxygen to strain-age cracking was concluded to be one of lowering the resistance to crack propagation. In addition, the role of weld energy was minimized. Reduction in weld energy will reduce the severity of cracking, but it is the least important and least controllable variable.

A state-of-the-art report on the fundamentals of brazing technology for nickel alloys, prepared by Sidney Kaufman, has been received by DMIC.(4) The report includes descriptions of brazing processes, designs, applications, and limitations.

ALUMINUM

The Feltman Research Laboratory recently completed a program to investigate the effects of relative humidity on the wettability and bondability of 2024 aluminum alloy.(5) Relative humidity was concluded to noticeably affect these properties on chemically etched aluminum surfaces. With polyamide-epoxy adhesives, wetting was improved under conditions of high humidity. Also, adhesive joints prepared under high relative humidity conditions were stronger than those produced under dry conditions. With Epon 828/Versamid 140 (70/30 ratio by weight) the following bond strengths were obtained in lap shear specimens:

1845 psi ± 206 at 20 percent relative humidity

2700 psi ± 238 at 100 percent relative humidity.

Welding processes have been investigated during a program at Battelle to produce high-quality electrical strip from ultrahigh-purity aluminum.(6) The strip is intended for use at low temperatures in magnet applications. The aluminum strip used in these studies had a guaranteed resistivity ratio (resistance at room temperature/resistance at liquid-helium temperature) of 7000 or above. Inert-gas tungsten-arc welding was used to join 0.06-inch-thick strips. Welding was performed in a vacuum chamber purged to about 2×10^{-5} torr and backfilled with

argon. Welds were made at 8.3 to 8.9 volts, 152 to 159 amperes, and 50 ipm, using 1/16-inch-diameter, 1 percent thoriated tungsten electrodes. The resistivity ratios of welded strips were better than 80 percent of the ratios of unwelded base metal. Mechanical properties of the strip at liquid-helium temperatures after annealing were not affected by the presence of a weld. Thermal cycling between room temperature and liquid-helium temperature apparently did not affect the properties. Satisfactory electron-beam welds with resistivity ratios comparable to those of the arc welds were also made. However, the TIG process was considered more practical and controllable.

REFRACTORY METALS

Northrop has completed a study of solid-state diffusion-bonding technology for T-111 (Ta-8W-2Hf) honeycomb hot-structural and heat-shield panels for aerospace environments.(7) Both flat and curved specimens were produced for each type panel. Diffusion bonding was done in a sealed envelope of 0.025-inch-thick Inconel 600 sheet using quartz-lamp radiant heating. Bonding parameters for 12-by-12-inch panels were:

Temperature - 2250 F

Time - 3.5 hours

Pressure - 1000 psi

Intermediate - 0.0015-inch Ti 55 (structural panels)

0.0005-inch Ti 75 (heat-shield panels).

Following bonding, the structural panels were hermetically sealed by inert-gas tungsten-arc welding. There were no difficulties with flat panels, but a cracking problem was encountered on curved panels. This was corrected by repair welding. Weld and parent-metal cracking were more of a problem on heat-shield panels. Gas tungsten-arc, laser, and electron-beam welding were all tried without success in attempts to solve this problem. The majority of welding was finally done by the electron-beam process, which minimized the cracking.

The structural panels were tested at room and elevated temperatures. This consisted of edgewise compression testing of curved panels and edgewise shear testing of flat panels. The panels were coated with Al-Sn-Mo for oxidation protection during testing. The curved panels failed at stresses of 91,700 psi and 71,600 psi at room temperature and at 17,200 psi at 2800 F. The flat panels failed at 74,500 psi and 81,520 psi at room temperature, 33,420 psi at 2100 F, and 13,400 psi at 2650 F.

Unalloyed tantalum has been satisfactorily brazed to Type 316 stainless steel in a program at NASA-Lewis.(8) Vacuum brazing was accomplished at 2150 F using J-8400 brazing alloy (Co-21Cr-21Ni-8Si-3.5W-0.4C-0.8B). When flat sheet and tubular specimens were tested at 1350 F in a vacuum chamber (10^{-7} to 10^{-6} torr), all joints failed in the tantalum or stainless steel parent metal. There was no unfavorable diffusion observed between the braze alloy and the parent metals.

Solar has developed a brazing process for attaching internal fins of Cb-1Zr foil to Cb-1Zr heat-receiver tubes.(9) In brazing tests on T-joint and lap-joint specimens of Cb-1Zr, 15 braze alloys (copper, gold, titanium/zirconium, and zinc bases) were evaluated. The three alloys that performed most satisfactorily in these tests and the average tensile shear strengths of brazed joints are:

Cu-2Ni - 38,100 psi

Zr-25V-16Ti - 38,500 psi

Zr-25V-16Ti-0.1Be - 37,600 psi.

Because of its braze fluidity and filleting characteristics, the Zr-25V-16Ti-0.1Be alloy was used to braze full-scale heat-receiver tubes. Brazing was performed satisfactorily at 2130 F for 5 minutes in an induction furnace at a vacuum pressure of 1×10^{-5} torr. The specimens were enclosed in cylindrical tantalum susceptors to insure uniform and rapid heating.

The diffusion bonding of columbium and tantalum to themselves and to each other was investigated at RAI Research Corporation.(10) The investigators concluded that with these materials, a diffusion-bonding regime exists in which the joining process is primarily diffusion controlled. Within this regime, the use of certain filler metals substantially reduces the time and temperature at which bonding takes place. The temperature at which diffusion-controlled bonding occurs is substantially lower than the recrystallization temperature of the parent metals in the work-hardened condition, 419 C (754 F) compared to 600 C (1112 F) for columbium and 800 C (1472 F) for tantalum. Using aluminum foils, good lap bonds were obtained in all three material combinations (columbium-columbium, tantalum-tantalum, columbium-tantalum) in 1/2 hour at 2000 psi and 419 C. At the same conditions, no bonds were obtained in 2 hours without foil. Butt joints made using the aluminum foil had tensile strengths of 12,000 psi for columbium and 19,850 psi for tantalum. The joint efficiency was poor because only a small fraction of available contact areas (from 10 to no more than 50 percent) was bonded. Oxidation was believed to be the cause of this poor efficiency. Stricter atmosphere control and cleanliness procedures were suggested as means to improve joint strength and bond efficiency.

NEW PROGRAMS

Materials Development

Contract NAS3-11827 Weldability Study of T-111 and Astar 811-C, Westinghouse Electric Corporation, June 14, 1968.

Contract NAS8-21470, Effects of Hydrogen on Unprotected Titanium Alloy Weldments, Mc Donnell-Douglas Corporation, June 27, 1968.

Contract NAS8-8327, Testing of PH14-8Mo Stainless Steel Honeycomb Sandwich Core Shear Strength, North American Rockwell Corporation, June 27, 1968.

Electron-Beam Welding

Contract F33615-68-C-1466, Equipment and Materials for Development of Large Chamber Electron-Beam Welding, General Electric, Missiles and Space Division, April 10, 1968.

Contract AF 33(615)-66-05277, Portable Local Chamber Electron-Beam Welding (extension of previous program), Sciaky Brothers, Inc., May 24, 1968.

Resistance Welding

Contract N0024-68-C-5314, An Automatic Tee-Welder for Submarine Hull Welding Systems for Shipyard Use, Battelle Memorial Institute, May 29, 1968.

Miscellaneous

Contract F04611-68-C-0077, Cold Welding Research, Philco-Ford Corporation, Space and Reentry Systems Division, May 22, 1968.

Contract F33615-68-C-1545, Wire Fabric Joining, Aerojet-General Corporation, May 24, 1968.

Contract F33615-67-C-1562, Design and Structural Analysis for Utilization of Fiber Reinforced Composite Materials for Aircraft Structural Joints and Cutouts, McDonnell-Douglas Corporation, June 17, 1968.

Contract F33615-68-C-1664, Development of Titanium Tube Welding, North American Rockwell Corporation, June 28, 1968.

REFERENCES

(1) Yount, R. E., Kutchera, R. E., and Keller, D. L., "Development of Joining Techniques for TD Nickel-Chromium", Report AFML TR 67-224, General Electric Company, Evendale, O., Contract AF 33(615)-3476 (October 1967).

(2) Buckmann, O. A., "Development of Manufacturing Processes for a Lightweight Heat Transfer System", Final Report AFML TR 67-300, Part I, The Garrett Corporation, Los Angeles, Calif., Contract AF 33(615)-1926 (December 1967).

(3) Thompson, E. G., Nunez, S., and Proger, M., "Practical Solutions to Strain-Age Cracking in René 41", Welding Journal, 47 (7), 299s-313s (July 1968).

(4) Kaufman, S., "Practical Fundamentals of Protective Atmosphere Brazing of Nickel Alloys", Report WAPD T-1947, Atomic Power Division, Westinghouse Electric Corporation, Pittsburgh, Pa., Contract AT-11-1-Gen-14 (September 1966).

(5) Barbarisi, M., and Hall, J. R., "Effect of Relative Humidity on Adhesive Bonding of Aluminum Alloy", Technical Memorandum 1785 (AD 662747), Picatinny Arsenal, Dover, N. J. (December 1967).

(6) Preliminary information from Columbus Laboratories, Battelle Memorial Institute, Columbus, O. on U. S. Air Force Contract AF 33(615)-5270.

(7) Hugill, D. B., and Shabarack, J., "Solid-State Diffusion Bonded Tantalum Alloy Honeycomb Panels", Final Report AFML TR 68-42, Norair Division, Northrop Corporation, Hawthorne, Calif., Contract AF 33(615)-2777 (March 1968).

(8) Spagnuolo, A. C., "Evaluation of Tantalum-to-Stainless Steel Transition Joints", Report TM X-1540, NASA, Lewis Research Center, Cleveland, O. (April 1968).

(9) Smeltzer, C. E., and Compton, W. A., Development of a Brazing Process for Cb-1Zr Heat Receiver Tubes", Final Report RDR 1611, Solar Division, International Harvester Company, San Diego, Calif., Contract NAS 3-10603 (May 1, 1967 - January 31, 1968).

(10) Korman, S., Keusch, P., and Gonzalez, C., "Research Study of Diffusion Bonding of Refractory Materials, Columbium and Tantalum", Final Report AMMRC CR-67-15(F), RAI Research Corporation, Long Island City, N. Y., Contract DAAG 46-67-C-0020 (November 10, 1967).

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